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ScienceDirect
Energy Procedia 75 (2015) 853 – 859
Energy Procedia

The 7th International Conference on Applied Energy – ICAE2015

A new adsorption process to intensify liquefied petroleum gas recovery from raw natural gas

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Abstract

Raw natural gas from gas wells typically consists of methane, gaseous hydrocarbons, acid gases, water, liquid hydrocarbons, *etc*. The raw natural gas must be purified to produce the pipeline quality dry natural gas for residential, commercial and industrial consumers. The existing natural gas processing often roughly separates the raw natural gas into gaseous phase dry natural gas and liquid-phase gas condensate without extracting the high-priced liquefied petroleum gas (LPG). And thus, the LPG is sold along with cheaper dry gas and natural gas condensate. In addition, the gas condensate, in which LPG components like propane and butane, are often stored under atmospheric pressure, and most LPG components will be burnt after escaping from the breathing valve, which will also harm the environment. Some companies have tried to add LPG production line by adding more columns, which is not feasible economically. We present a new chemical adsorption flowsheet to enhance the LPG recovery. A comparison between the two processes is made, and the result shows that the chemical adsorption process is highly economical.

Peer-review under responsibility of Applied Energy Innovation Institute

Key words: natural gas, LPG, recovery.

1. Introduction

The principal constituent of raw natural gas is methane, and other constituent can vary widely. The typical makeup of raw natural gas includes methane, gaseous hydrocarbons, acid gases, nitrogen, helium, water, liquid hydrocarbons, and mercury [1]. Besides dry natural gas, sulfur, ethane, and natural gas condensate are often produced as byproducts from the processing of raw natural gas. Liquefied petroleum

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Peer-review under responsibility of Applied Energy Innovation Institute
doi:10.1016/j.egypro.2015.07.183

gas (LPG) is widely used as rural heating, motor fuel, and cooking [2]. And LPG is regarded as a key medium-term option in the transition to sustainable fuels and transport [3]. And thus, the production of LPG is more profitable than both natural gas and gas condensate.

However, the LPG components, mainly propane and butane, are not extracted enough and mostly either sold along with the gas and gas condensate or burnt by the flaring. In the last few decades, extensive studies have been conducted on natural gas processing. These studies can be generally classified into two categories, including natural gas purification and transmission.

Several researchers have studied the natural gas dehydration and desulfurization. The conventional dehydration methods include absorption, adsorption, refrigeration and membranes [4]. Several novel separation methods like supersonic separators in the natural gas dehydration for fewer emissions and better energy efficiency are also presented [5-6]. Crespo measured the sulfur adsorption capacity for various sorbent materials and found the promising sorbents for natural gas desulfurization [7]. Bhandari suggested a new sorption platform utilizing hollow fibers and explore the effect of fiber shape on desulfurization performance [8]. The optimization of natural gas pipeline network has also been the subject of much research. Nimmanonda used computer-aided simulation model to optimize the network system operation [9]. Chaczykowski presented an exergy-based analysis of gas transmission to compare the performance of gas transmission system under different conditions [10].

However, little research was devoted to increase the LPG production of the natural gas processing. This paper presents a new enhanced chemical adsorption flowsheet to enhance the LPG recovery. We first extract parameters of a conventional natural gas processing flowsheet and make an analysis of its production distribution and energy utilization. After that, a new flowsheet with same feedstock and operating conditions is put forward. Process simulation is applied to obtain adequate required data to make the comparison.

2. The analysis of an existing natural gas processing plant

An industrial natural gas processing plant is shown as the black part in Fig. 1, which indicates how raw natural gas is separated and purified to produce dry natural gas, LPG and gas condensate. Raw gas transmitted from pipeline system first undergoes phase separation, and the phase separation process includes slug catcher and three-phase separator. The raw gas is roughly divided into three parts, the gaseous, the liquid and water. The gaseous is dehydrated in the triethylene glycol (TEG) contact tower to produce pipeline-quality dry natural gas for civil use. In addition, the methane and ethane dissolving in the condensate are separated in the C2 removal tower and compressed to the pipeline system. The remnant condensate is fed into the C4 removal tower where LPG is distillated from the top. Finaly, the LPG is transported to the storage tank after desulfurization.

In order to precisely present the composition of the raw natural gas, pseudo component blend is used to represent the complex heavy components. ASTM D86 test method is applied to obtain the distillation curve type of blend, and the specific gravity of blend is 0.8032. Table 1 lists the distillation percent of blend with varying temperature. Table 2 is the material balance of the original flowsheet, from which we can find out the propane and butane distribution. Table 3 is the description of the design specifications for columns. Process simulation often fails to converge due to recycle streams in process flowsheet [11]. In this study, there is one recycle stream in the flowsheet, recycle gas condensate. To solve the convergence problem, the recycle streams are split in the simulation model, and connected to reach a total convergence till the difference between the values of split streams are very close. This simulation approach has been widely used [12]. The spilt streams are listed in the feed and product streams and named as S401 and S402, respectively. As shown in the Table 2, only 33% of propane and butane are extracted to the LPG storage while the rest are all separated into the dry gas and transmitted to the pipeline system.

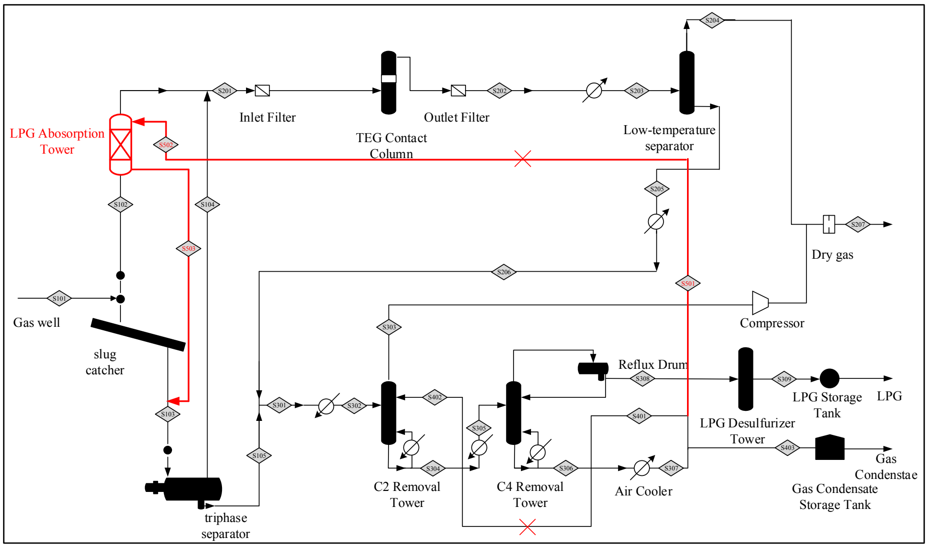

Fig. 1. Flowsheet of original and new natural gas processing

Table 1. Distillation percent of blend under varying temperature

Temperature/ºC	70	115	155	218	249
Percent distilled/%	5	40	70	90	98

Table 2. Parameters of original process flowsheet

Stream types	Feeds		Products			
Stream	S101	S402	S207	S309	S403	S401
Temperature / °C	54.3	35.0	-0.1	48.9	210.8	35.0
Pressure / Mpag	6.89	1.40	5.60	1.12	1.15	1.40
Mass rate / (tonne/day)	1172.41	321.50	1033.54	15.66	123.71	320.00
Nitrogen /(tonne/day)	12.56	0.00	12.56	0.00	0.00	0.00
Carbon Dioxide / (tonne/day)	217.70	0.00	217.69	0.02	0.00	0.00
methane/(tonne/day)	723.36	0.00	723.36	0.00	0.00	0.00
Ethane / (tonne/day)	45.53	0.00	45.23	0.30	0.00	0.00
propane/ (tonne/day)	25.66	0.00	18.83	6.82	0.00	0.00
n-Butane/(tonne/day)	9.57	0.00	4.91	4.20	0.13	0.33
i-Butane /(tonne/day)	10.50	0.00	4.41	4.16	0.54	1.40
n-Pentane/(tonne/day)	4.72	0.00	1.02	0.03	1.02	2.65
i-Pentane/(tonne/day)	2.74	6.59	0.79	0.02	2.37	6.15
Hexane/(tonne/day)	4.41	15.75	0.46	0.00	5.48	14.21
heptane/(tonne/day)	2.96	0.00	0.02	0.00	0.82	2.12
Octane/(tonne/day)	0.51	0.00	0.00	0.00	0.14	0.37
Nonane/(tonne/day)	0.12	0.00	0.00	0.00	0.03	0.09
Blend/(tonne/day)	112.08	299.15	4.26	0.12	113.18	293.68

Table 3. The specifications of C2 and C4 removal towers

Columns	Pressure / MPa(g)	Stage number	Feed stage	Design specifications distillate	Bottom
C2 Removal	1.38	34	14	mass fraction of C3 and C4 ≤0.01	mass flowrate of C2≤0.3 tonne/day
C4 Removal	1.12	44	21	mass fraction of C3 and C4 ≥0.95	mass flowrate of C3 and C4 ≤2 tonne/day

3. The enhanced LPG recovery process

Considering the unsatisfactory recovery of LPG, a LPG absorption tower is added to absorb the LPG in the gas from the slug catcher with cooling gas condensate. As shown the red part in Fig. 1, the gas condensate enters the LPG absorption tower absorbing the LPG components and mixes with the liquid-phase from the slug catcher. The new flowsheet shares the same column design specifications with the original one as shown in Table 3.

The LPG components recovered are highly relevant to the physical conditions and flow rate of recycling condensate. Thus, a sensitivity analysis of LPG components mass is conducted with varying recycling condensate flow rate. The gas condensate temperature is cooled to 35 °C and pumped to be able to enter the tower. The absorption tower is treated as a flash drum with baffles, and assumed to be a Radfrac distillation with 3 theoretical stages in simulation. Fig. 2 illustrates that the flow rate of C3 and C4 in gas decreases as the recycling flow rate increases. However, constrained by the existing equipment, the recycling volume cannot be greater than the capability of the C2 and C4 removal columns and pipelines. As a result, 500 tonne per day is determined as the recycling flow rate. Table 4 present the simulation results of the new flowsheet, and over 61% of C3 and C4 are extracted to the LPG storage tank. The additional absorbing tower design parameters are evaluated based on Sounders-Brown equation and the capital cost is calculated to be € 35000 considering the evaluated design parameters[13].

Table 4. Parameters of new process flowsheet

Stream types	Feeds			Products				
Stream	S101	S402	S502	S207	S309	S403	S401	S501
Temperature / °C	54.3	35.0	35.0	1.2	51.9	214.6	35.0	214.6
Pressure / MPa(g)	6.89	1.40	6.90	5.60	1.12	1.15	6.90	1.15
Mass rate / (tonne/day)	1172.41	997.67	500.00	1025.33	32.00	114.76	998.00	500.00
Nitrogen /(tonne/day)	12.56	0.00	0.00	12.56	0.00	0.00	0.00	0.00
Carbon Dioxide / (tonne/day)	217.70	0.00	0.00	217.69	0.01	0.00	0.00	0.00
methane/(tonne/day)	723.36	0.00	0.00	723.36	0.00	0.00	0.00	0.00
Ethane / (tonne/day)	45.53	0.00	0.00	45.28	0.26	0.00	0.00	0.00
propane/ (tonne/day)	25.66	0.00	0.00	11.16	14.49	0.00	0.00	0.00
N-Butane/(tonne/day)	9.57	0.00	0.00	1.65	7.62	0.02	0.19	0.10
I-Butane /(tonne/day)	10.50	0.00	0.00	0.98	7.89	0.12	1.01	0.50
N-Pentane/(tonne/day)	4.72	6.12	3.07	0.85	0.36	0.90	7.86	
I-Pentane/(tonne/day)	2.74	12.91	6.47	1.15	0.12	1.48	12.91	6.47
Hexane/(tonne/day)	4.41	35.72	17.90	0.80	0.00	4.07	35.41	17.74
heptane/(tonne/day)	2.96	7.55	3.79	0.05	0.00	1.01	8.82	4.42
Octane/(tonne/day)	0.51	0.00	0.00	0.00	0.00	0.04	0.32	0.16
Nonane/(tonne/day)	0.12	0.00	0.00	0.00	0.00	0.01	0.07	0.04
Blend/(tonne/day)	112.08	935.37	468.78	9.87	1.26	107.10	931.43	466.65

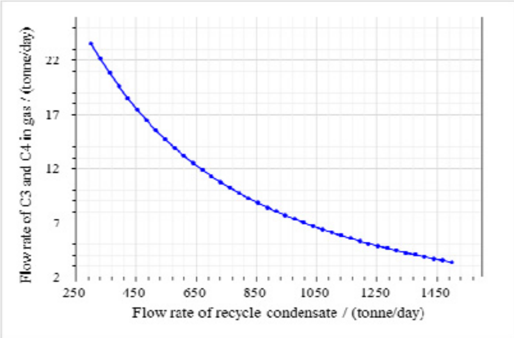

Fig. 2. Sensitivity analysis of flow rate of C3 and C4 in gas

4. Comparison of the two process performance

Table 5 shows the results of two process flowsheet products flowrate, and the price is offered by the enterprise. The adding profit for new flowsheet is 2487.5 euro per day. To further compare the economic benefits, utility system expense is considered. The pinch analysis has been made in Aspen Energy Analyzer when the minimum approach temperature is 8.9 °C. The least utilization is then determined for both flowsheets by using the stream data tabulated in Table 6. The hot and cold utilities requirement is 1.26 and 3.01 MW for the original flowsheet, and 5.58 and 7.13 MW for the new flowsheet. As shown in Table 6, the increasing heating utility mainly results from the increasing feed flowsheet of C2 and C4 removal towers, and the cooling utility increased is mainly caused by the ail cooling from S306 to S307.

Table 5. The products flowrate and prices

Flowsheet	Dry gas S207 /tonne·day^{-1}	Dry gas /euro·tonne^{-1}	LPG S309 /tonne·day^{-1}	LPG /euro·tonne^{-1}	Condensate S403 /tonne·day^{-1}	Condensate /euro·tonne^{-1}
Original	1034	575	16	725	124	437.5
New	1025		32		115	

Table 6. Stream data for original flowsheet extracting from process simulation.

Items	Original flowsheet			New flowsheet		
	Inlet T /°C	Outlet T /°C	Enthalpy /MW	Inlet T /°C	Outlet T /°C	Enthalpy /MW
C2 reboiler	178.6	201.0	0.80	189.8	215.5	3.97
C4 condenser	58.1	48.9	0.31	60.1	52.0	0.92
C4 reboiler	195.0	210.9	0.79	199.6	214.6	2.86
S202-S203	25.3	-31.0	1.99	35.4	-31.0	2.18
S204-S207	-39.9	-2.2	1.16	-39.8	-2.2	1.07
S205-S306	-39.9	143.3	0.40	-39.8	143.3	0.41
S301-S302	99.4	207.2	0.67	70.3	207.2	3.21
S304-S305	201.0	185.0	0.24	215.5	185.0	1.65
S306-S307	210.9	35.0	2.13	214.6	35.0	7.90
triphase separator	25.6	60.0	0.10	26.8	60.0	0.58

5. Conclusion

This study paper present an enhanced liquefied petroleum gas recovery process. Two processes are fully simulated under the same feedstock and product specifications. For further comparison, we extract the process data and perform energy analysis and economic evaluation. Two conclusions can be drawn from this study. Firstly, the reabsorption of LPG is feasible by the recycling of gas condensate, and the LPG recovered increased with the recycling flowrate. Secondly, the enhanced recovery can lead to better quality of dry gas and extract more LPG to sell. Thirdly, the capital cost of the additional tower is approximately 35000 euro, the new process can increase revenue from better LPG recovery by 2487.5 euro per day, which justifies the additional capital cost of tower and utility. Although the overall energy consumption increases, the prospect benefit is considerable.

6. Copyright

Acknowledgements

This research is supported by the National Natural Science Foundation of China (No. 21376277), and the project of the Science and Technology Star of Zhujiang of Guangzhou City (No. 2013J2200006).

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Biography

Bing Jian Zhang was born in HuBei (China) in 1978. He received his PhD in Chemical Engineering from South China University of Technology (2006). Since 2011 he is associate professor of chemical engineering in Sun Yat-Sen university. His main research interests are process integration and energy system optimization for process industries.